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Drift velocity measurements of various materials floating on water waves

Paul Keith Scherrer

DRIFT VELOCITY MEASUREMENTS OF VARIOUS MATERIALS

FLOATING ON WATER WAVES

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Darryl Alofs (Advisor) R F Rueslin

J. F. Stauffer

ABSTRACT

A study was conducted to determine the affects of deep water gravity waves on oil lenses and surface floats. The experiment was conducted in a wave tank equipped with a mechanical wave generator. The data obtained consisted of the measured velocities of oil lenses and thin plastic floats under the action of a variety of wave conditions.

It was found that waves do cause a movement of the oil lenses and surface floats, and their velocity was found to be greater than the surface drift predicted by Stokes' theory of mass transport by waves in a single component fluid. For wave conditions at which the Stokes' velocity is higher than 2 centimeters per second, the measured velocities of the surface floats were 35 to 150 percent greater than the Stokes' velocity.

It was also found that the oil lenses traveled at about the same velocity as flexible plastic floats of the same length. The drift velocity of the floats increased with increases in float length in the regime where the float length was smaller than the length of waves used. For float length greater than the wave length, the drift velocity was insensitive to float size.

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I. INTRODUCTION

In the past few years there has been an increasing public awareness of the ocean pollution caused by oil spills. Attention was focused on this problem very dramatically when the Torrey Canyon went aground off the coast of England spilling almost thirty million gallons of oil. It was estimated that the Torrey Canyon spill cost the British government eight million dollars, but the cost to society was even greater due to the loss of water birds and fish, as well as, defacing the beaches where the oil washed up.

Accidents involving oil tankers are not the only cause of oil spills. There are presently 14,000 off-shore oil wells in the territorial waters of the United States. Off-shore drilling accidents have periodically polluted the West and Gulf Coasts with large oil slicks. With more off-shore drilling platforms being erected and the number and size of oil tankers being increased, one can see that oil spills on the ocean is an increasing menace to the environment.

Once an oil spill has occurred, it is imperative that cleanup operations be immediately undertaken to minimize damage. The ability to predict the movement of an oil slick would be of great value in this undertaking for two reasons. Firstly, predicting the path that an oil slick will follow is a necessary step in the mobilization of cleanup resources. Secondly, if the origin of an oil spill could be accurately determined, the party responsible for the oil spill could be notified and asked to assist in the cleanup operations.

At the present time some attempts have been made to correlate oil spill movements with local wind conditions. In the book Torrey Canyon Pollution and Marine Life (J. E. Smith, 1968) the movement of some of the oil spilled from the Torrey Canyon was correlated to wind direction and velocity. A correlation was obtained by assuming that the oil spill moved at 3.3% of the wind velocity and in the direction of the wind. There were, however, significant deviations between the actual path of the oil spill and that predicted by the 3.3% wind velocity correlation. Alofs and Reisbig (1971) examined the deviations and concluded that they were probably caused by wave effects.

The deep water wave theory of G. G. Stokes predicts that the water particles in a wave experience a net drift in the wave propagation direction. The net drift velocity in a single component fluid is given by Stokes (1847) by the following expression:

$$V_s = \pi^2 (H/L)^2 C \exp(-4\pi Y/L)$$

Where: V is the mass transport velocity

H is the wave height

L is the wave length

C is the wave velocity

Y is the distance below the surface of the wave

By setting Y equal to zero in the above equation, the velocity of the water particles on the surface of the wave is obtained.

Assuming that the oil spill will move at the same velocity as the water beneath it, theoretical calculations can be made to determine to what extent waves might affect oil spills. These theoretical calculations, made by Alofs and Reisbig (1971), indicate that waves could affect oil spills as much as does the wind.

II. REVIEW OF LITERATURE

Credit for the first wave theory can be given to Franz Gerstner of Czechoslovakia. In 1802 he noted that individual water particles in waves moved in circular paths with closed orbits and the orbit of the water particles at the surface of a wave had a diameter equal to the wave height. He also pointed out that the particles in the crest move in the direction of the wave and those in the trough move in the opposite direction.

In 1845 a British professor, G. G. Stokes, realized that the orbits made by the water particles in a wave do not close, and that the water particles experience a net movement in the direction of the waves. Stokes' theoretical solution of the mass transport caused by waves is based upon the assumption that the fluid is inviscid and irrotational and that the occillatory waves are deep water waves. Mitchim (1940) carried out experimental work in 1938 and 1939 that verified Stokes' theory.

Longuet-Higgens (1953) took viscous effects into account in a more recent analysis of wave induced surface drift. Huang (1970) criticized the Longuet-Higgens solution because according to it the drift velocity should increase with the depth of the water. This would mean that as the water gets infinitely deep the surface velocity would approach infinity, which is a physical impossibility. Although the Longuet-Higgens solution is not applicable to deep water waves, Russell and Osorio (1957) have experimentally verified it for shallow water conditions.

Both Mitchim (1940) and Russell and Osorio (1957) let their wave generator run continuously while they were taking data. In this steady-state condition the net mass flux across any vertical plane must be zero. Since the waves cause a forward flow at the surface, a backward flow must exist at some lower water level. Mitchim (1940) reported that this back flow was near the bottom in his tank but Russell and Osorio (1957) reported it near the center depth of their tank. Since on the open ocean the net mass flux across any vertical plane does not have to equal zero, avoidance of this backward flow in the wave tank would be desirable.

Chang (1969), like Longuet-Higgens, considered viscous effects in his analysis of the surface transport velocity. In his solution he found that the surface transport velocity was essentially the same as given by Stokes' theory. Still another theoretical investigation in which viscous effects were considered has been reported by Huang (1970). His analysis is especially useful because it can be used for any value of kd ($kd = 2\pi d/L$, d is the water depth, L is the wavelength). Huang found that for a clean surface the surface velocity asymptotically approached Stokes' surface velocity for $kd >> 1$. For a dirty surface he found that for $kd >> 1$ the surface velocity approached 5/4 of that predicted by Stokes' theory. Unluata and Mei (1970) raised some questions about the free surface conditions used by Huang and presented their own solution of the problem, but their solution is not for large values of kd and thus does not shed much light on deep water conditions encountered in the ocean.

As can be seen from the above mentioned literature, opinions are quite varied in regard to mass transport by waves. In the experimental investigations mentioned above, the velocity of small floats or neutrally buoyant particles were measured. However, these experiments cannot be directly applied to the case of an oil slick, because an oil layer might not travel at the same velocity as the water beneath it. All these considerations led to the undertaking of the experiment described below.

III. APPARATUS

The experiment was performed in a wave tank (Figure 1) 6.1 meters long, 0.30 meters wide and 0.61 meters deep. The vertical side walls were constructed of glass except for the section in which the wave generator was contained. The glass walls were necessary to facilitate the study of currents in the channel, as well as the measurement of the wave height. The paddle used to produce the waves was driven by a variable speed motor and was located 25.4 centimeters from one end of the tank. At the other end of the tank was a sloping beach to suppress wave reflection. The tank was covered with a clear plastic sheet to help keep the surface of the water from being contaiminated by dust.

The velocity of the surface floats was determined by timing them as they traveled through the "test section" of the tank. This test section was 0.61 meters long and started 2.18 meters from the paddle. By having the test section located in this part of the tank it was isolated from the undesirable currents that exist near the paddle and beach.

At the beach end of the tank two 1.27 centimeter diameter drains were placed at water level. These drains were closed except during the skimming operation, at which time the beach was lowered below water level and air was blown across the surface of the water. This forced all the surface contaminates toward the beach end of the tank where they were drawn off through the drains.

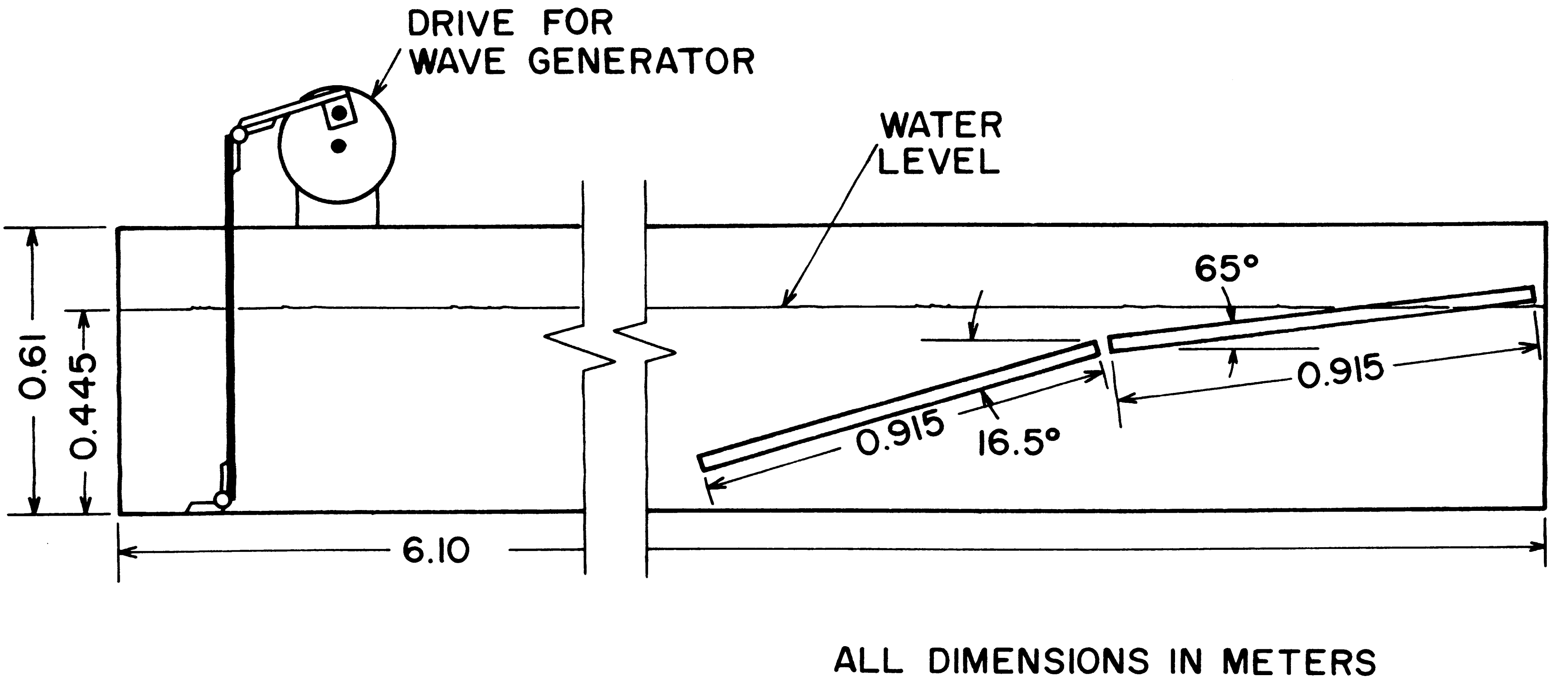

Fig. 1. Schematic of Wave Tank

In the experiment two types of surface floats were used, oil lenses and flexible plastic floats. The oil lenses used were made of paraffin oil. This oil does not contain any detergents which would cause it to continuously spread when placed upon the water. Therefore the lenses formed with it were dimensionally stable. The other type of float was a flexible plastic float having one side smooth (the side in contact with the water) and the other side quilted. The plastic material used consisted of two sheets of plastic bonded together so that air cells, 0.7 centimeters on a side, were formed between the two sheets making the thickness of the total quilted material 0.015 centimeters. This material is used commercially for wrapping food.

IV. PROCEDURE

With the water in the wave tank being quiescent, an oil lens or flexible plastic float was carefully placed on the surface of the water about 30 centimeters upstream from the test section. The wave generator was then turned on and the first few waves brought the float into the test section. The float was then timed with a stopwatch as it traveled through the 61 centimeters long test section. This terminated the test run. The 30 centimeters distance mentioned above assures that the waves are uniform by the time the float enters the test section. As reported by Pottinger (1972), this conclusion was reached by examining photographs of the waves which contained chalk dust particles.

By turning the wave generator off between runs and allowing the surface to become quiescent two adverse conditions were avoided. First, the backflow currents that were reported by Mitchim (1940) and Russell and Osorio (1957) were not present in the test section. This conclusion was reached (Pottinger, 1972) after studying numerous time exposure photographs of chalk dust particles sprinkled in the water. The study of these photographs indicated that the undesirable backflow currents developed in the tank only after the wave generator had been running for approximately 5 minutes. In this experiment, the wave generator was never on for more than two minutes during any data run so this backflow was not present.

The other adverse effect that would result from leaving the wave generator run continuously is the buildup of surface contaminants toward the beach end of the tank. Just as the waves carry the surface floats toward the beach, they also transport any particles of dust that may be on the surface. It was found that after the wave generator had been running for some time, these contaminants became so concentrated at the beach end of the tank that they stopped and even reversed the forward movement of the float.

In the procedure used, however, the wave generator was not on more than two minutes during any data run, thus there wasn't enough time for the contaminants to become densely packed at the beach end of the tank. Moreover, the contaminants that did build up were allowed to disperse by letting the surface become quiescent between runs. Using this procedure it was found that the float velocities were the same before and after the water in the tank was changed and the tank cleaned. Thus it was concluded that contaminants did not influence the float movement using the above procedure.

V. RESULTS

In order to check for a sidewall boundary layer in the tank, three oil lenses 1.27 centimeters in diameter were placed on the surface of the water. They were placed at points 2.54 centimeters, 8.5 centimeters and 15 centimeters from the wall of the tank. The tank was 30 centimeters wide so the lens 15 centimeters from the wall was at the center of the tank. The wave generator was then turned on and the lenses were timed as they traveled through the test section. It was found that the lenses at 8.5 centimeters and at 15 centimeters from the side of the tank traveled at the same velocity. Moreover, their position with respect to the wall was not altered during the course of the run. The oil lens that was 2.54 centimeters from the wall, however, traveled slower than the other two and moved away from the wall in the course of the run.

The largest displacement of one of these lenses from the wall was found for a wavelength of 50.8 centimeters and steepness of 0.054. For this case the oil lens closest to the wall was displaced away from the wall continuously, until it was 8.3 centimeters from the wall, at the end of the test section. This indicated that the boundary layer was at most 8.3 centimeters wide in the test section. The usable width of the tank (13.4 centimeters) was then found by subtracting twice the width of the boundary layer from the tank width. Therefore, to insure that the wall boundary layer would not affect the velocity of the oil lenses, the lenses used were less than 13.4 centimeters in diameter.

During the course of the runs, the oil lenses did not remain circular in shape but were distorted by wave action. The radius of curvature of the lenses was smaller at the edge where the waves were leaving the lens than where they were entering it, thus giving the lens a wedge shape. In addition to this steady-state distortion, the passing waves caused the shape of the lens to alternate from an elliptical shape with major axis in the direction of wave motion at the crest to an elliptical shape with major axis perpendicular to the wave motion at the trough. These elliptical shapes are probably due to gravity since oil placed on a curved surface would act similarly.

Although the waves did distort the lenses, the lens thickness remained uniform. This conclusion was reached by examining pictures of the movement of oil lenses made partially opaque by mixing bone-black into the oil. Since the color of these lenses was uniform over the lens area except at the edge of the lenses, it was concluded that their thickness remained uniform.

Data for relatively small oil lenses is shown in Figure 2, which is a plot of oil lens velocity versus Stokes' surface velocity for 3 ml. (4.58 cm. in diameter) and 10 ml. (7.50 cm. in diameter) oil lenses. Figure 2 shows that the measured oil lens velocity was always greater than Stokes' surface velocity. This result together with the calculations by Alofs and Reisbig (1971) indicates that waves do have a significant influence on oil spill movements on the open ocean. It is also interesting to note that in most cases the larger lenses (10 ml.) traveled faster than the smaller lenses (3 ml.).

Figures 3 and 4 show the wave conditions under which the data in Figure 2 was obtained. Figure 3 is for 3 ml. oil lenses and Figure 4 is for the 10 ml. lenses. The wave steepness (H/L) is plotted on the absissa and the lens velocity is plotted on the ordinate for the various wavelengths shown. The Stokes' surface velocity (solid lines) is plotted for wavelengths of 50.8 centimeters and 25.4 centimeters, the extreme wavelengths for which data was taken.

Since the data presented in Figure 2 indicates that the lens velocity depended on the lens size, it was worthwhile to obtain data on a larger range of oil lenses than those covered in Figure 2. This data is shown in Figure 5, where one can clearly see that the velocity of the oil lens increases with increases in size. It is, however, physically impossible for the lens velocity to keep increasing with lens size, because oil spills on the ocean would then move at an almost infinite velocity. The lens diameter at which the lens speed becomes insensitive to lens size could not be determined with the oil lenses due to the narrow width of the tank. As mentioned previously, the largest diameter lens that could be used was 13.4 centimeters in diamter. Therefore, other means were used to investigate this question.

One suspects that it is the float length rather than float width that is influencing float speed. In order to test this

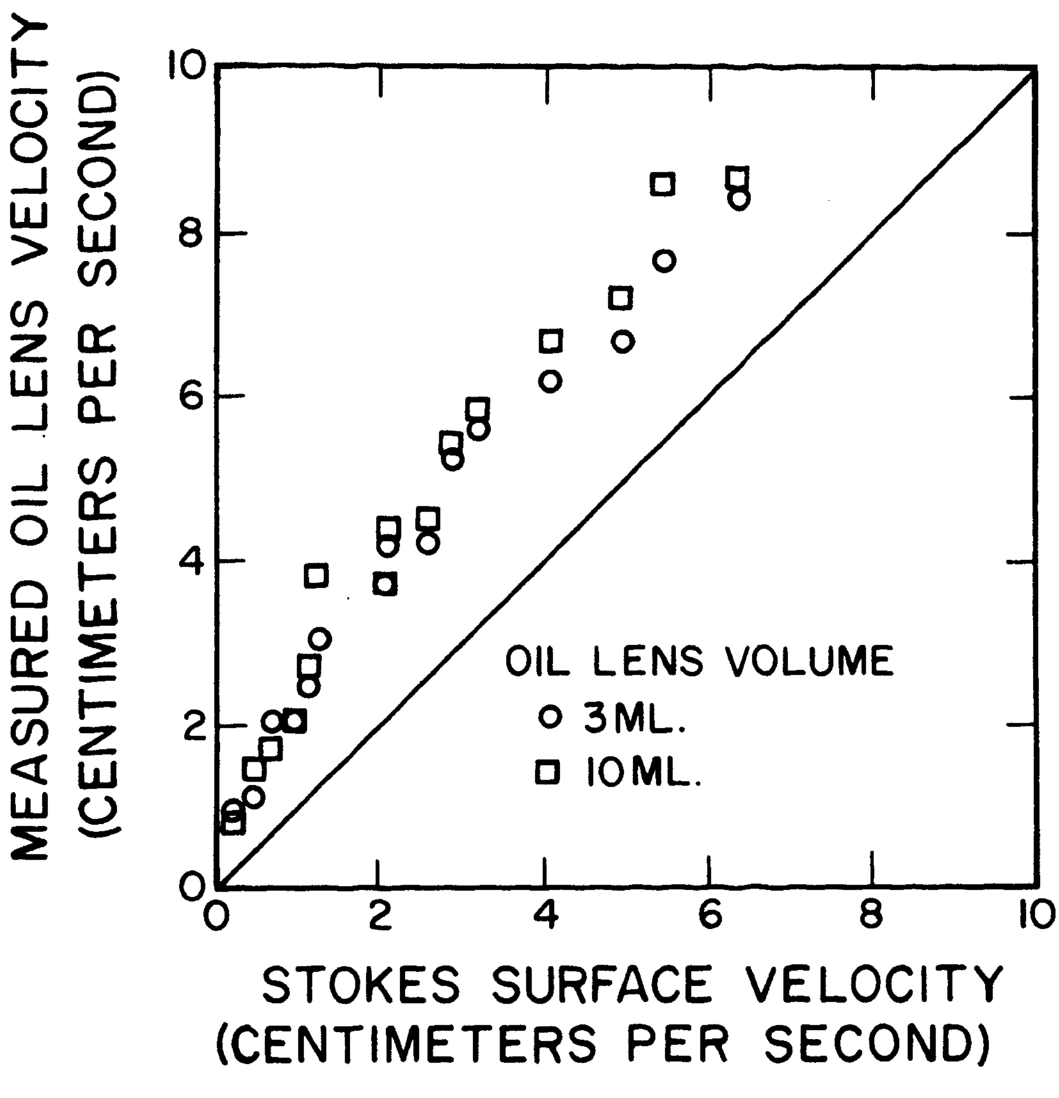

Fig. 2. Comparison of oil lens velocity with the Stokes' Velocity

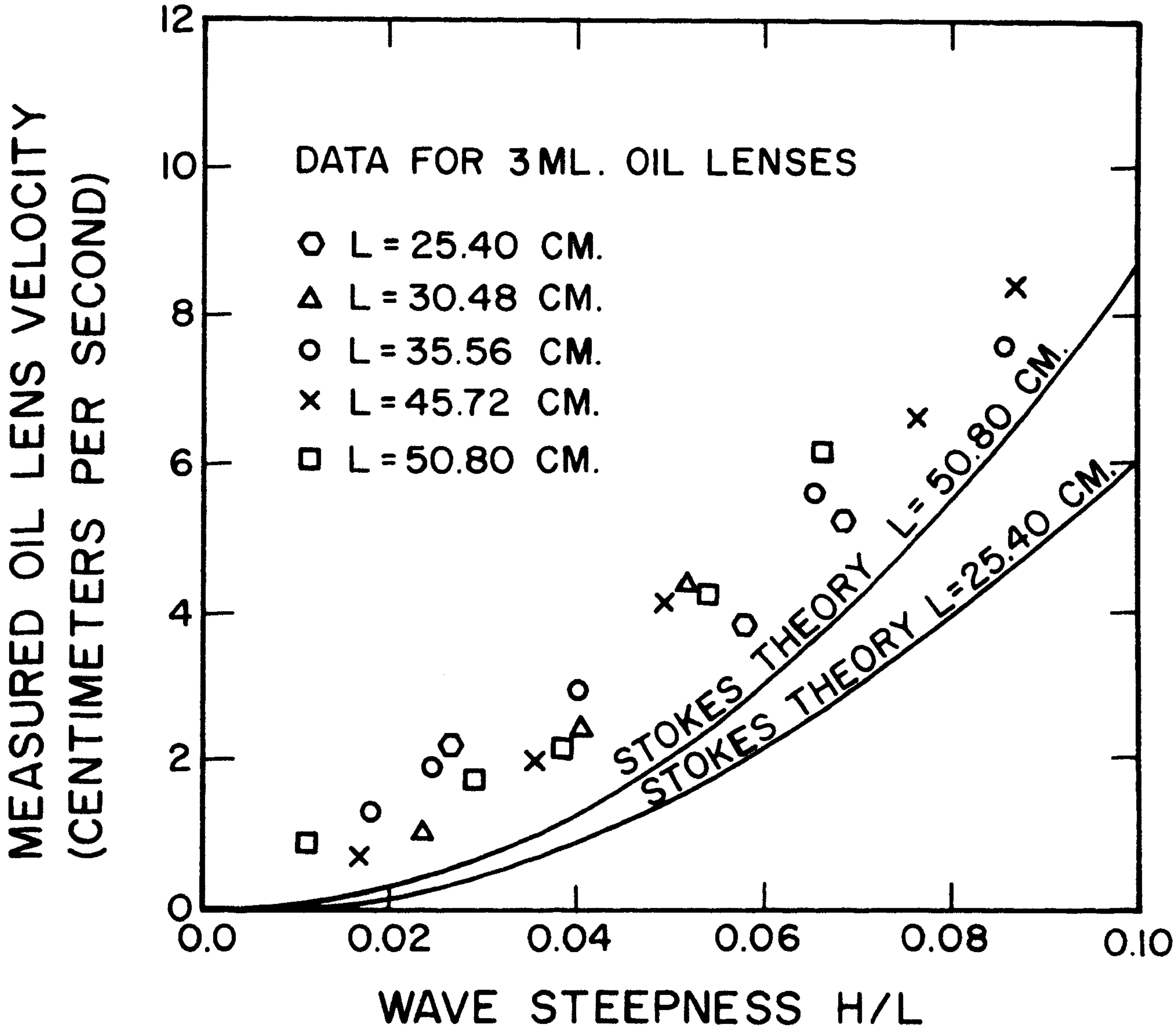

Fig. 3. Wave Conditions for the 3 ml Oil Lens Data

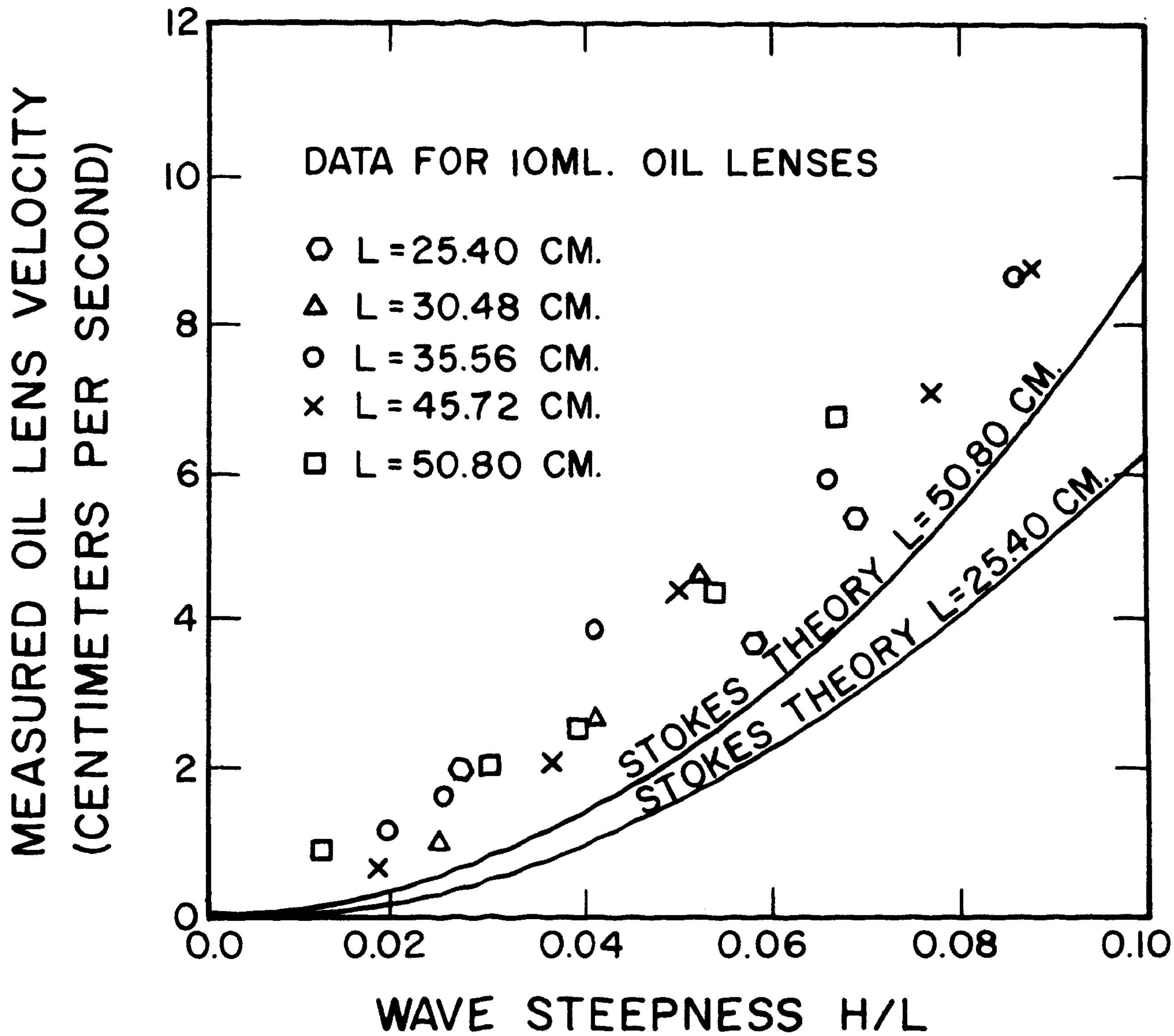

Fig. 4. Wave Conditions for the 10 ml Oil Lens Data

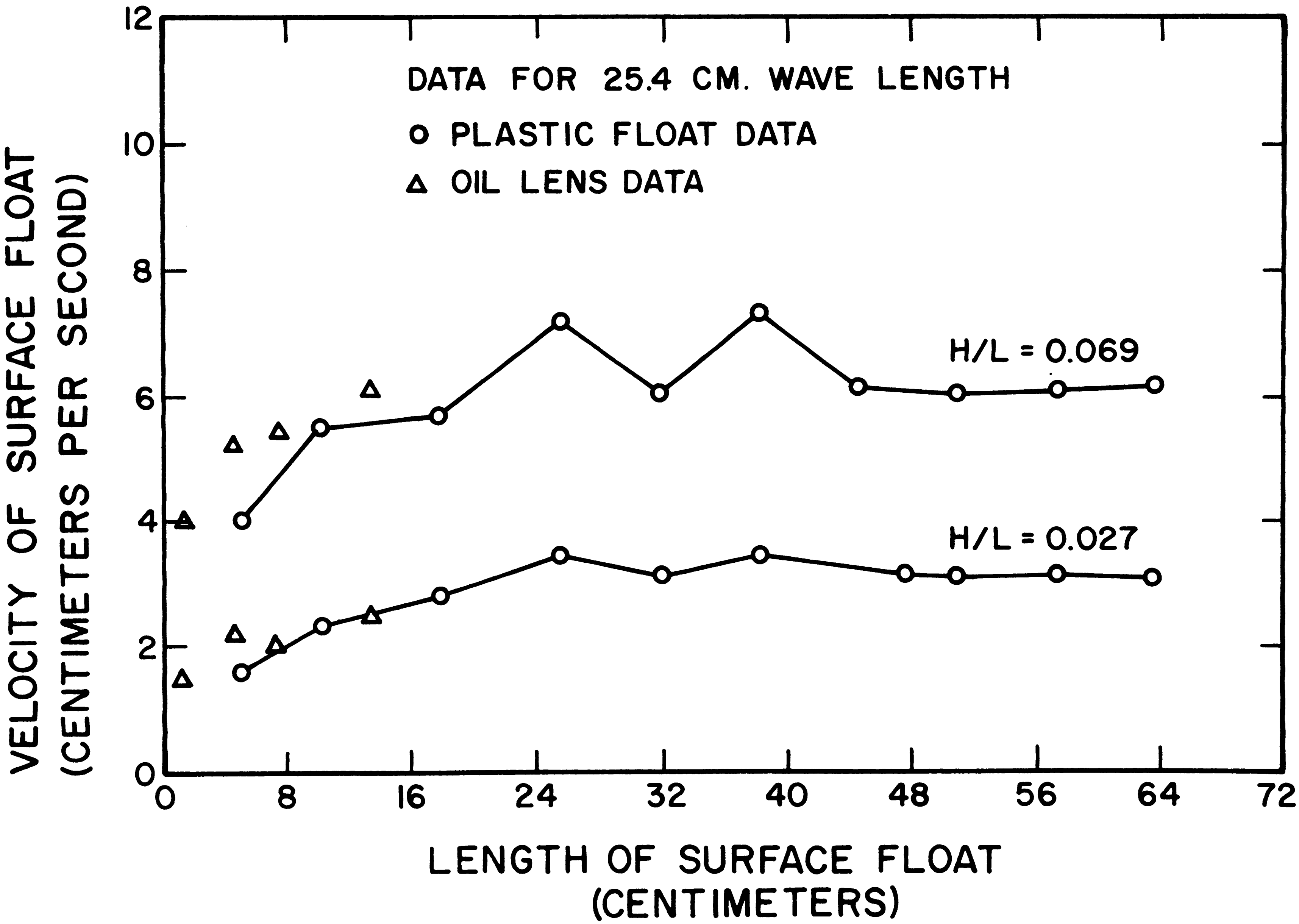

Fig. 5. Velocity of Surface Floats Versus Length of Surface Floats for 25.4 Centimeter Wave Length

hypothesis, it was desirable to find some material that was flexible like oil, but would not spread, so that narrow lengths of it could be formed. The material chosen was the flexible plastic mentioned previously. The plastic floats were all 4.8 centimeters wide and varied in length from 4.8 centimeters to 76.2 centimeters. These plastic floats were used in obtaining the data shown in Figures 5 and 6. It can be seen from Figure 5 that the velocity of the plastic floats, like the oil lenses, increased with increases in float length in the region where the float length was smaller than the length of the waves used. For float lengths greater than the wave length, the drift velocity was insensitive to float size.

Figure 6 is also a plot of the velocity of the surface float versus the length of the surface float, but this one is for a wavelength of 50.8 centimeters. Figure 6, like Figure 5, shows that the larger oil lenses had a larger drift velocity than the smaller ones. It also shows that with increases in float length the velocity of the plastic floats increased and then leveled off when the float length approached the wavelength.

The next question is, will an oil lens travel at the same velocity as a plastic float of length equal to the oil lens diameter. It can be seen from both Figures 5 and 6 that the oil lenses traveled about the same velocity as the flexible plastic floats of the same size. This seems to indicate that the velocity does not depend on the material as such, as long as it is flexible and does not deeply penetrate the water's

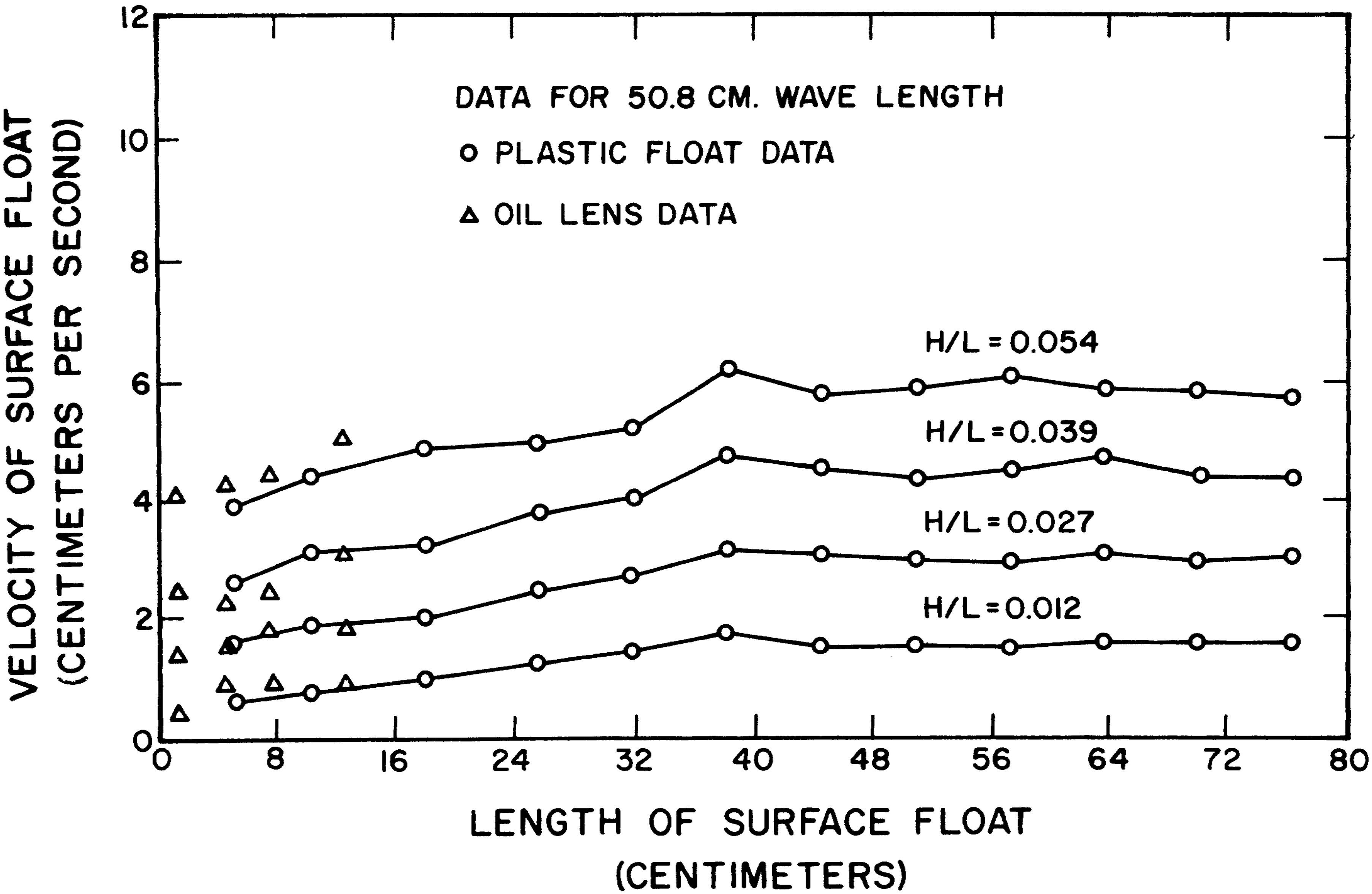

Fig. 6. Velocity of Surface Floats Versus Length of Surface Floats for 50.8 Centimeter Wave Length

surface. This is of practical importance in that the properties of oil spills vary widely from one spill to the next. The fact that drift speed is insensitive to float material and float size means that the same correlation can be applied to almost any oil spill on the ocean.

VI. CONCLUSIONS

All the data is listed in the Appendix. An examination of this data indicates that the velocity of the surface floats were in all cases greater than the surface drift predicted by Stokes' theory of mass transport. Percentage deviations between the measured drift velocities and the Stokes' velocities are also listed in the Appendix. For wave conditions at which the Stokes' velocity is higher than 2 centimeters per second, the measured velocities of the surface floats were 35 to 150 percent greater than the Stokes' velocity. In previous experimental investigations the surface drift was found to be very close to that predicted by Stokes' theory. The difference in results can be attributed to two things different in this experiment than in previous ones, floats and procedure.

In this experiment the surface floats used were made of oil and plastic. Both of these were flexible and covered a larger area than the floats used in previous experiments. Secondly, the procedure followed in this experiment eliminated the backflow current that was reported in previous experiments. Therefore, this experiment may be more representative of the conditions that exist on the open ocean.

The experiment strongly indicates that for increases in float length greater than the wave length the drift velocity is insensitive to float size. The experiment also indicates that the float velocity is independent of the float material as long as it does not penetrate too deeply into the water. The conclusions of float speed insensitivity to float size and float material are of great practical importance because they reduce the number of parameters needed in any scheme to predict oil spill movements on the ocean.

BIBLIOGRAPHY

Alofs, D.J., and R.L. Reisbig, "The Affects of Waves on Oil Spill Movements," Proceedings of a Symposium on Technology for the Future Control of Industrial Wastes, University of Missouri-Rolla, Rolla, Missouri, February 8-9, 1971.

Chang, M.S., (1969), "Mass Transport in Deep-Water Long-Crested Random Gravity Waves," J. Geophys. Res., 74, 1515-1536.

Huang, N.E., (1970), "Mass Transport Induced by Wave Motion," J. Marine Res., 28, 35-40.

Longuet-Higgins, M.S., (1953), "Mass Transport in Water Waves," Phil. Trans. Roy. Soc. London, A, 245, 535-581.

Mitchim, C.F., (1940), "Oscillatory Waves in Deep Water," The Military Engineer, 32, 107-109.

Pottinger, J.M., (1972), "Experimental Analysis of Surface Drift Caused by Water Waves," Masters Thesis, University of Missouri-Rolla.

Russel, R.C.H., and J.D.C. Osorio, (1957), "An Experimental Investigation of Drift Profiles in a Closed Channel," Proceedings of the Sixth Conference on Coastal Engineering, Council on Wave Research, University of California, Berkeley, 171-183.

Smith, J.E., (editor), (1968), Torrey Canyon, Pollution and Marine Life, Cambridge University Press, London, 196.

Stokes, G.G., (1847), "On the Theory of Oscillatory Waves," Cambridge Phil. Soc., 8, 441-455.

Unluata ,U., and C.C. Mei, (1970), "Mass Transport in Gravity Waves," J. Geophys. Res., 75, 7611-7618.

VITA

Paul Keith Scherrer was born on June 6, 1949 in St. Louis, Missouri. He received his primary education at Immaculate Conception School in Arnold, Missouri and graduated from St. Pius X High School, Festus, Missouri in June, 1967.

He entered the University of Missouri - Rolla, in Rolla, Missouri, in September 1967. In May, 1971, he received a Bachelor of Science degree in Mechanical Engineering from the University. In June, 1971, he enrolled in the Graduate School of the Mechanical Engineering Department.

APPENDIX

TABLES

TABLE I

Lens Volume Versus Lens Diameter for Paraffin Oil at 77°F

Lens Volume	Lens Diameter
4 drops	1.27 centimeters
3 milliliters	4.58 centimeters
10 milliliters	7.50 centimeters
40 milliliters	12.43 centimeters

TABLE II

Three Milliliter Oil Lens Data

(This data is graphically shown in Figures 2 and 3)

L, Wave Length (cm.)	H/L Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	V_L, Lens Velocity (cm./sec.)	V_L-V_S (cm./sec.)	$\frac{V_L-V_S}{V_S}$
25.40	0.027	0.457	2.26	1.803	3.945
"	0.069	2.95	5.21	2.26	0.8726
30.48	0.024	0.406	1.12	0.714	1.759
"	0.052	1.83	4.39	2.56	1.399
35.56	0.019	0.279	1.30	1.021	3.659
"	0.041	1.27	2.95	1.68	1.323
"	0.066	3.18	5.59	2.41	0.7579
"	0.086	5.49	7.62	2.13	0.3880
45.72	0.017	0.229	0.864	0.635	2.773
"	0.033	0.914	2.08	1.166	1.276
"	0.050	2.08	4.22	2.14	1.029
"	0.077	4.90	6.68	1.78	0.3633
"	0.087	6.27	8.46	2.19	0.3493
50.80	0.012	0.127	0.856	0.729	5.740
"	0.027	0.635	1.47	0.835	1.315
"	0.039	1.34	2.24	0.900	0.6716
"	0.054	2.57	4.24	1.67	0.6498
"	0.067	4.01	6.15	2.14	0.5336

TABLE III

Ten Milliliter Oil Lens Data

(This data is shown graphically in Figures 2 and 4)

L, Wave Length (cm.)	H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	V_L, Lens Velocity (cm./sec.)	$V_L - V_S$ (cm./sec.)	$\frac{V_L - V_S}{V_S}$
25.40	0.027	0.457	2.00	1.543	3.376
"	0.069	2.95	5.31	2.36	0.800
30.48	0.024	0.406	1.067	0.661	1.628
"	0.052	1.83	4.52	2.69	1.470
35.56	0.019	0.279	1.19	0.911	3.265
"	0.041	1.27	3.86	2.59	2.039
"	0.066	3.18	5.82	2.64	0.8302
"	0.086	5.49	8.53	3.04	0.5537
45.72	0.017	0.229	0.838	0.609	2.659
"	0.033	0.914	2.08	1.166	1.276
"	0.050	2.08	4.29	2.210	1.063
"	0.077	4.90	7.01	2.11	0.4306
"	0.087	6.27	8.53	2.26	0.3604
50.80	0.012	0.127	0.864	0.737	5.803
"	0.027	0.635	1.75	1.115	1.756
"	0.039	1.34	2.44	1.100	0.8209
"	0.054	2.57	4.39	1.820	0.7082
"	0.067	4.01	6.63	2.62	0.6534

TABLE IV

Oil Lens Data for Wave Length of 25.4 Centimeters
(This data is shown graphically in Figure 5)

H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	Lens Diameter (cm.)	V_L Lens Velocity (cm./sec.)	$V_L - V_S$ (cm./sec.)	$\frac{V_L - V_S}{V_S}$
0.027	0.457	1.27	1.55	1.093	2.392
"	"	4.58	2.26	1.803	3.945
"	"	7.50	2.00	1.543	3.376
"	"	12.43	2.45	1.993	4.361
0.069	2.950	1.27	3.96	1.01	0.3424
"	"	4.58	5.21	2.26	0.7661
"	"	7.50	5.31	2.36	0.8000
"	"	12.43	6.10	3.15	1.068

TABLE V

Oil Lens Data for Wave Length of 50.8 Centimeters

(This data is shown graphically in Figure 6)

H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	Lens Diameter (cm.)	V_L, Lens Velocity (cm./sec.)	$V_L - V_S$ (cm./sec.)	$\frac{V_L - V_S}{V_S}$
0.012	0.127	1.27	0.43	0.303	2.385
"	"	4.58	0.86	0.733	5.772
"	"	7.50	0.86	0.733	5.772
"	"	12.43	0.89	0.763	6.008
0.027	0.635	1.27	1.36	0.725	1.142
"	"	4.58	1.47	0.835	1.315
"	"	7.50	1.75	1.115	1.756
"	"	12.43	1.80	1.165	1.835
0.039	1.340	1.27	2.49	1.150	0.8582
"	"	4.58	2.24	0.900	0.6716
"	"	7.50	2.44	1.100	0.8205
"	"	12.43	3.05	1.710	1.276
0.054	2.570	1.27	4.09	1.52	0.5914
"	"	4.58	4.24	1.67	0.6498
"	"	7.50	4.39	1.82	0.7082
"	"	12.43	5.04	2.47	0.9611

TABLE VI

Plastic Float Data for Wave Length of 25.4 Centimeters

(This data is shown graphically in Figure 5)

H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	Float Length (cm.)	V_F Float Velocity (cm./sec.)	$V_F - V_S$ (cm./sec.)	$\frac{V_F - V_S}{V_S}$
0.027	0.457	5.08	1.58	1.123	2.457
"	"	10.16	2.32	1.863	4.077
"	"	17.78	2.79	2.333	5.105
"	"	25.40	3.45	2.993	6.549
"	"	31.75	3.10	2.643	5.783
"	"	38.10	3.45	2.993	6.549
"	"	47.63	3.18	2.723	5.958
"	"	50.80	3.15	2.693	5.893
"	"	57.15	3.18	2.723	5.958
"	"	63.50	3.06	2.603	5.695
0.069	2.950	5.08	4.04	1.09	0.3695
"	"	10.16	5.54	2.59	0.8779
"	"	17.78	5.38	2.43	0.8237
"	"	25.40	7.19	4.24	1.437
"	"	31.75	6.07	3.12	1.058
"	"	38.10	7.39	4.44	1.505
"	"	44.45	6.15	3.20	1.085
"	"	50.80	5.99	3.04	1.031
"	"	57.15	6.12	3.17	1.075
"	"	63.50	6.25	3.30	1.119

TABLE VII

Plastic Float Data for Wave Length of 50.8 Centimeters
(This data is shown graphically in Figure 6)

H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	Float Length (cm.)	V_F, Float Velocity (cm./sec.)	$V_F - V_S$ (cm./sec.)	$\frac{V_F - V_S}{V_S}$
0.012	0.127	5.08	0.61	0.483	3.803
"	"	10.16	0.76	0.633	4.984
"	"	17.78	1.02	0.893	7.031
"	"	25.40	1.24	1.113	8.764
"	"	31.75	1.45	1.323	10.42
"	"	38.10	1.76	1.633	12.86
"	"	44.45	1.53	1.403	11.05
"	"	50.80	1.53	1.403	11.05
"	"	57.15	1.55	1.423	11.20
"	"	63.50	1.60	1.473	11.60
"	"	69.85	1.55	1.423	11.20
"	"	76.20	1.57	1.443	11.36
0.027	0.635	5.08	1.57	0.935	1.472
"	"	10.16	1.88	1.245	1.961
"	"	17.78	2.01	1.375	2.165
"	"	25.40	2.49	1.855	2.921
"	"	31.75	2.73	2.095	3.299
"	"	38.10	3.12	2.485	3.913
"	"	44.45	3.05	2.415	3.803
"	"	50.80	2.95	2.315	3.646

TABLE VII (Continued)

H/L, Wave Steepness	V_S, Stokes' Velocity (cm./sec.)	Float Length (cm.)	V_F, Float Velocity (cm./sec.)	V_F-V_S (cm./sec.)	$\frac{V_F-V_S}{V_S}$
0.027	0.635	57.15	2.92	2.285	3.598
"	"	63.50	3.05	2.415	3.803
"	"	69.85	2.95	2.315	3.646
"	"	76.20	3.06	2.425	3.819
0.039	1.340	5.08	2.59	1.25	0.9328
"	"	10.16	3.07	1.73	1.291
"	"	17.78	3.25	1.91	1.425
"	"	25.40	3.78	2.44	1.821
"	"	31.75	3.99	2.65	1.978
"	"	38.10	4.76	3.42	2.552
"	"	44.45	4.48	3.14	2.343
"	"	50.80	4.38	3.04	2.269
"	"	57.15	4.46	3.12	2.328
"	"	63.50	4.72	3.38	2.522
"	"	69.85	4.38	3.04	2.269
"	"	76.20	4.36	3.02	2.254
0.054	2.570	5.08	3.91	1.34	0.5214
"	"	10.16	4.37	1.80	0.7004
"	"	17.78	4.83	2.26	0.8794
"	"	25.40	4.93	2.36	0.9183
"	"	31.75	5.13	2.56	0.9961
"	"	38.10	6.17	3.60	1.401
"	"	44.45	5.74	3.17	1.233
"	"	50.80	5.87	3.30	1.284
"	"	57.15	6.02	3.45	1.342
"	"	63.50	5.82	3.25	1.265
"	"	69.85	5.77	3.20	1.245
"	"	76.20	5.69	3.12	1.214